ERG

**MEMORANDUM**

**TO:** Jay Garland, EPA
Cissy Ma, EPA
Michael Jahne, EPA

**FROM:** Citizen Name / Ex. 6

**SUBJECT:** **Life Cycle Assessment of Atmospheric Water Generation Technologies and Alternative Potable Water Emergency Response Options**

**DATE:** March 15, 2018

Under Task 2b of EPA Contract No. EP-C-15-010 and Subcontract No. PO ERG-18-001 ERG is supporting EPA and Pegasus Technical Services in the development of life cycle assessments (LCA) and cost assessments of atmospheric water generation (AWG) technologies. AWGs are an emerging technology option for responding to emergency situations in which safe municipal treated drinking water is not accessible. This study will compare various AWG scenarios with bottled water as an emergency response option. This memorandum presents the intended study goal, scope, and methods.

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# 1. Introduction and Study Goal

This study will evaluate the use of AWG technology in comparison with bottled water as an emergency response option to provide clean and safe drinking water. The primary goal of this study is to perform an LCA to evaluate the environmental impacts including fossil fuel usage, water consumption and deprivation, air and water quality, and cumulative energy use of several AWG scenarios in comparison with those of bottled water. In addition, we propose to carry out a life cycle cost analysis (LCCA) of multiple scenarios for both emergency response options.

**Commented [JM1]:** EPA domain?

# 2. Scope of AWG Analysis

This section summarizes the scope of the AWG analysis, including the functional unit (i.e., basis of results), system boundaries of analysis, impact assessment categories, and potential data sources.

## 2.1 Functional Unit

To provide a basis for comparison of different products, a common reference unit must be defined. The reference unit is based upon the function of the products, so that comparisons of different products are made on a uniform basis. This common basis, or functional unit, is used to normalize the inputs and outputs of the LCA, with all results expressed on a functional unit basis. Because the goal of AWG systems and bottled water is to deliver clean and safe drinking water, the functional unit of this study is one liter of potable water. There may be differences in the water quality characteristics of the AWG product versus bottled water. Such variations will not affect the functional unit but will be summarized in the study to the extent possible. Note that bottled water and AWG product are not managed by EPA's National Primary Drinking Water Regulations. Bottled water is regulated by the Food and Drug Administration (FDA).

**Commented [JM2]:** AWG would be if serves >15 people

## 2.2 AWG System Boundaries

The system boundaries of an AWG system are shown in Figure 1. The system boundaries start at production of the AWG unit, and continue through transport to point of use, water generation, maintenance, and disposal of the AWG unit at end-of-life. Material, fuel, energy, and chemical inputs as well as air, water and waste outputs across all life cycle stages of the AWG will be incorporated in the analysis. AWG infrastructure burdens will be accounted for by amortizing infrastructure impacts by the useful life of the AWG unit and then standardizing results based on the functional unit of one liter of delivered potable water.

Figures 2, 3 and 4 show the unit processes of three different AWG units developed by Water-Gen, EcoloBlue and Aqua Sciences respectively. The specific treatment of the water prior to delivery depends on the AWG vendor and unit scale. A summary of potential vendors and unit scales to incorporate in the study is listed in Section 3.1.

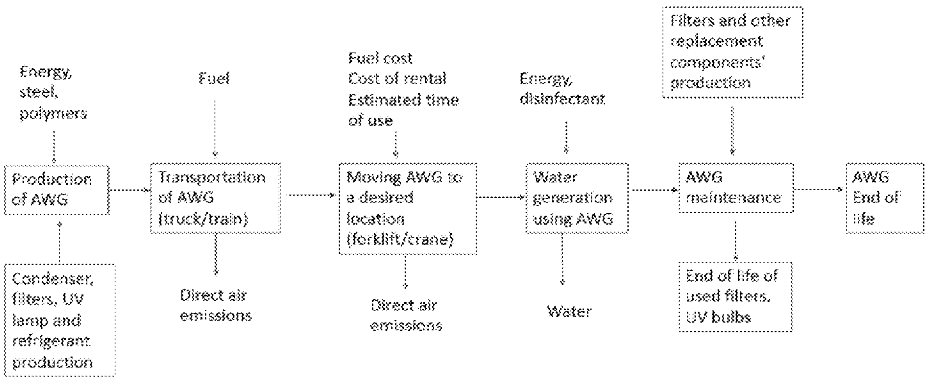


**Figure 1. System Boundaries for Atmospheric Water Generator**

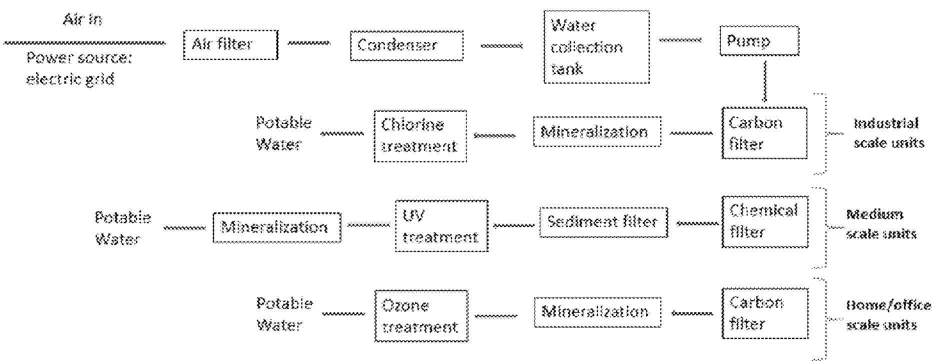


**Figure 2. Schematic Overview of AWG Unit Operation – Water-Gen**

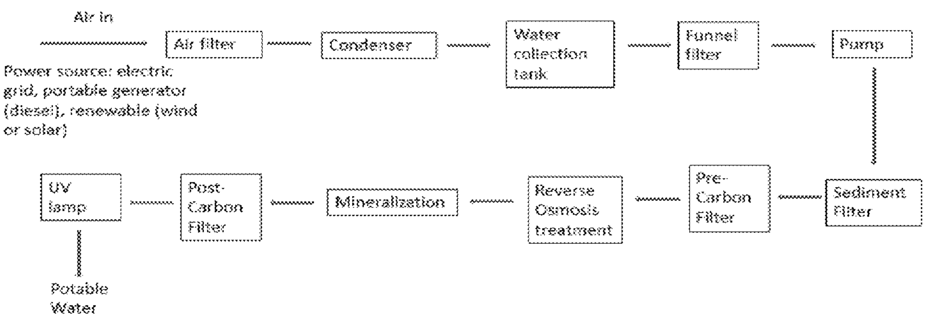


**Figure 3. Schematic Overview of AWG Unit Operation – EcoloBlue (All Scales)**

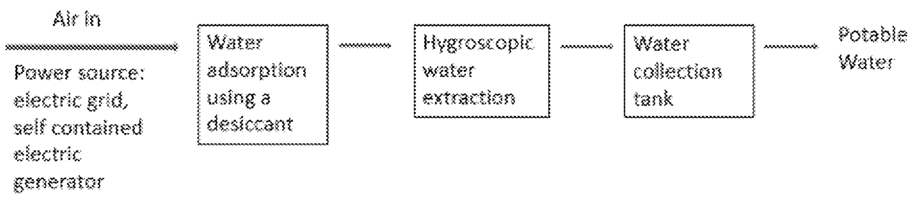


**Figure 4. Schematic Overview of AWG Unit Operation – Aqua Sciences**

## 2.3 Impact Assessment Categories

The Impact categories and methods to be applied in this study are shown in Table 1. Results of this study will address global, regional, and local impact categories. The first impact category to be assessed is cumulative energy demand (CED) using a cumulative energy inventory method, which accounts for the total primary energy consumption of renewable and non-renewable energy resources. The second impact category is fossil fuel depletion, which will be assessed using a midpoint indicator in the ReCiPe 2016 impact assessment method to calculate the systems' demand for non-renewable fossil-based energy resources such as oil, coal, and natural gas (Huijbregts et al., 2016). The impact category of water consumption will be assessed by using the inventory water consumption method and water deprivation impact category will be measured by applying AWARE method, which quantifies the water stress impacts of water consumption.[1] The weight of solid waste will also be calculated by summing the inventory of solid waste by weight flows for all stages across the AWG's life cycle. EPA's TRACI v2.1 (i.e., Tool for Reduction and Assessment of Chemicals and Other Environmental Impacts) method will be applied to account for the acidification, eutrophication, smog formation and particulate matter formation potential of the systems being analyzed (Bare, 2003). In addition, a life cycle cost analysis will help determine the most cost-effective option among different competing alternatives for the function they are intended to serve.

**Table 1. Scope of Impact Assessment**

| Category | Unit | Method | Description |
|---|---|---|---|
| **Cumulative Energy Demand** | MJ | Cumulative energy inventory | The cumulative energy demand indicator accounts for the total usage of non-renewable fuels (natural gas, petroleum, coal, and nuclear) and renewable fuels (such as biomass and hydro). Energy is tracked based on the heating value of the fuel utilized from point of extraction, with all energy values summed together and reported on a MJ basis. |
| **Fossil Fuel Depletion** | kg oil eq. | ReCiPe | Fossil fuel depletion captures the consumption of fossil fuels, primarily coal, natural gas, and crude oil. All fuels are normalized to kg oil equivalent (eq) based on the heating value of the fossil fuel and according to the ReCiPe impact assessment method. |

[1] AWARE scores can be found at the WULCA website, http://www.wulca-waterlca.org/project.html.

| | | | |
|---|---|---|---|
| **Water Consumption** | Liters $H_2O$ | Cumulative water consumption inventory | Freshwater withdrawals which are evaporated, incorporated into products and waste, transferred to different watersheds, or disposed into the sea after usage. |
| **Water Deprivation** | Stress-weighted Liters $H_2O$ eq. | AWARE | Quantifies the water stress impacts of water consumption based on the relative Available Water REmaining (AWARE) per area in a watershed, after the demand of humans and aquatic ecosystems have been met. |
| **Solid Waste by Weight** | kg | Cumulative solid waste inventory | The cumulative solid waste indicator sums up the total solid waste generated at each sub process of the product life cycle. |
| **Acidification Potential** | kg $SO_2$ eq | TRACI v2.1 | Quantifies the acidifying effect of substances on their environment. Important emissions: $SO_2$, $NO_x$, $NH_3$, HCl, HF, $H_2S$. |
| **Eutrophication Potential** | kg N eq. | TRACI v2.1 | Assesses impacts from excessive load of macro-nutrients to the environment. Important emissions: $NH_3$, $NO_x$, COD and BOD, N and P compounds. |
| **Smog Formation Potential** | kg $O_3$ eq. | TRACI v2.1 | Determines the formation of reactive substances (e.g. tropospheric ozone) that cause harm to human health and vegetation. Important emissions: $NO_x$, BTX, NMVOC, $CH_4$, $C_2H_6$, $C_4H_{10}$, $C_3H_8$, $C_6H_{14}$, acetylene, Et-OH, formaldehyde. |
| **Particulate Matter Formation Potential** | kg PM2.5 eq | TRACI v2.1 | Determines the effect of particulate matter (e.g., PM 2.5 and PM10) and pollutants which lead to respiratory impacts related to particulates (e.g., sulfur oxides and nitrogen oxides). |
| **Life Cycle Costs** | 2017 USD ($) | Life Cycle Cost Analysis | Determines the most cost-effective option among different competing alternatives to purchase, own, operate, maintain and, finally, dispose of an object or process, when each is equally appropriate to be implemented on technical grounds. |

## 2.4 Data Sources

ERG will use the following data sources to develop the inventory of inputs and outputs for the AWG LCA and LCCA:

- Equipment specifications and operational data provided by vendors listed in Section 3.1. ERG will require Aqua Sciences to provide specifications beyond what is publicly available in order to investigate this technology option.
- Primary measurement data from operation of the Water-Gen Gen350 medium scale AWG unit.
- Peer reviewed literature. Initial papers identified are as follows:
    - Peters, G. M., Blackburn, N. J., Armedion, M. (2013). Environmental assessment of air to water machines—triangulation to manage scope uncertainty. Int. J Life Cycle Assess 18, 1149–1157
    - Gido, B., Friedler, E., Broday, D. M. (2016a). Liquid-Desiccant Vapor Separation Reduces the Energy Requirements of Atmospheric Moisture Harvesting. Environ. Sci. Technol. 50, 8362–8367
    - Gido, B., Friedler, E., Broday, D. M. (2016b). Assessment of atmospheric moisture harvesting by direct cooling. Atmospheric Research 182, 156–162
    - Kumar, M., Yadav, A., Mehla, N. (2017). Water generation from atmospheric air by using different composite desiccant materials. International Journal of Ambient Energy, DOI: 10.1080/01430750.2017.1392350

- Bergmair, D., Metz, S. J., de Lange, H. C., Steenhoven, A. A. (2014). System analysis of membrane facilitated water generation from air humidity. Desalination 339, 26–33
- Milania, D., Qadira, A., Vassalloa, A., Chiesab, M., Abbasa, A. (2014.) Experimentally validated model for atmospheric water generation using a solar assisted desiccant dehumidification system. Energy and Buildings 77, 236–246
- Ozkan, O., Wikramanayake, E. D., Bahadur, V. (2017). Modeling humid air condensation in waste natural gas-powered atmospheric water harvesting systems. Applied Thermal Engineering 118, 224–232

For background processes such as material production, energy, and transport, ERG will use credible published life cycle inventory (LCI) databases. Wherever possible we will use data from publicly available sources, such as the U.S. LCI database (NREL, 2012) or the EPA Office of Research and Development (ORD) LCA Database. For unit processes for which public data are not available, we will clearly cite the private data sources and disclose as much information as possible without compromising the confidentiality of the data source. An example of a private LCI database is the Ecoinvent database (Weidema et al., 2013). Where data from the Ecoinvent database are used, we will adapt the data, so they are consistent with other data modules used in the study and representative of the energy production and transportation and, if applicable, industry practices in the U.S.

# 3. AWG Scenario Analysis

AWG LCA and LCCA results will be generated for a number of distinct scenarios in order to develop a comprehensive understanding of the likely range of environment and cost impacts from operating AWGs. The following sections summarize our recommended parameters to vary in the AWG analysis.

## 3.1 AWG Vendors and Unit Scales

The study will evaluate different AWG vendors to capture the range of potential environmental and cost impacts of this technology option. ERG, in coordination with EPA, has identified the following possible vendors:

- **Water-Gen:** Water-Gen manufactures AWG units of large, medium and home office scale. The large-scale or industrial scale units produce 6000L per day given optimum levels of temperature (27 degrees Celsius) and humidity (60 %) and can be installed on the rooftops of commercial buildings, in multiples, to meet high water demands. The medium scale unit, Gen350, is a portable AWG which can be mounted on a small truck or an SUV and allows for generation of up to 600 L water per day. The home or office scale unit, Genny, is able to generate 25-30 L of water daily (www.water-gen.com).

**Commented [JM3]:** Large truck required

- **Aqua Sciences:** Aqua Sciences manufactures a large-scale unit called the Emergency Water Station (EWS) capable of producing almost 1000L of water daily. This unit is powered by self-contained electrical generators or external power supply. This unit is designed to generate water in areas with very low humidity levels and damaged or no adequate infrastructure. The EWS uses a wet desiccant instead of a conventional refrigerant dehumidification system to generate water (www.aquasciences.com).

- **EcoloBlue:** EcoloBlue manufactures AWG units of large, medium and home office scale. The large-scale units range from 10,000 L produced per day to 1000L per day given optimum levels of temperature (30 degrees Celsius) and humidity (80 %). These units are scalable to meet high drinking water demands. The medium scale units or the light industrial series come in 100 L, 300L and 600L per day options. The home or office scale units can generate up to 30 L of water daily in optimal conditions. All EcoloBlue units are capable of integration with alternative power sources such as portable generators, wind and photovoltaic solar panels (ecoloblue.com).

### 3.2 Location of Manufacture and Use

ERG will include scenarios that consider different manufacture and use locations. Based on the identified vendors, ERG proposes the following manufacture locations be considered:

- Israel (Water-Gen)
- California, USA (EcoloBlue)
- Florida, USA (Aqua Sciences)

**Commented [JM4]:** Are they planning US though?

ERG will also include multiple options for location of AWG use as climate conditions such as temperature and relative humidity may affect the AWG performance. Most AWGs operate well in the temperatures ranging from 0 to 60 degrees Celsius and relative humidity between 25 and 100 percent. We will include two specific use locations:

- **Miami, FL USA.** Water-Gen has provided operational data for this location for the Gen350 medium scale unit.
- **Cincinnati, OH USA.** Water-Gen has provided EPA with a medium scale Gen350 unit to collect operational data in this location.

The above locations will be most applicable for data developed for the Gen350 unit. The relative humidity and temperature may vary slightly for LCAs developed for other AWG units and/or vendors based on available data. However, ERG will at minimum attempt to model all vendor-unit combinations under a warm climate (e.g., Miami, FL USA) and a cold climate (e.g., Cincinnati, OH USA).

### 3.3 Electrical Grid

The baseline results will model AWG operation using the average U.S. electrical grid fuel mix. The current electrical grid mix comprises largely of fossil fuels with highest dependency on natural gas (33.8 percent) followed by coal (30.4 percent). Nuclear energy contributes 19.8 percent to the grid and all other renewable energy sources make up 28.7 percent which include hydro, solar, wind and bio-mass. The sub-region FRCC ALL which includes Florida is of interest for data development for Gen350 unit so we can also model the electric grid mix of Florida. This sub-region produces the most electricity in the country after Texas and derives two-thirds of its electricity from natural gas, followed by coal, nuclear power and renewables respectively. The renewable energy is sourced primarily from biomass, hydro power and solar energy. Another area of interest for this study is the sub-region RFCW where Cincinnati, OH is located. The details of the resource mix for the average U.S. and the two sub-regions is shown in Table 2. Manufacture of the AWG unit will be modeled in the LCA using the electrical grid of the country of manufacture.

If of interest to EPA, ERG can incorporate a scenario modeling a 100% renewable electrical option. This scenario would assume the AWG is not connected to the electrical grid, but rather derives energy from an on-site diesel generator or a photovoltaic (PV) system. The EcoloBlue unit is capable of full integration with portable renewable energy options. ERG could include a case study investigating the EcoloBlue units powered by a diesel generator.

**Table 2. EPA eGRID U.S. and Two Sub-Regions Electricity Generation Resource Mix 2016**

| eGRID subregion acronym | eGRID subregion name | Generation Resource Mix (percent)* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Coal** | **Oil** | **Gas** | **Other Fossil** | **Nuc-lear** | **Hydro** | **Biomass** | **Wind** | **Solar** | **Geo-thermal** | **Other unknown/ purchased fuel** |
| **U.S. Average** | | **30.4** | **0.6** | **33.8** | **0.3** | **19.8** | **6.4** | **1.7** | **5.6** | **0.9** | **0.4** | **0.1** |
| **FRCC** | FRCC All | 16.0 | 1.2 | 66.6 | 0.0 | 12.8 | 0.1 | 2.4 | 0.0 | 0.1 | 0.0 | 0.7 |
| **RFCW** | RFC West | 49.8 | 0.4 | 16.7 | 0.7 | 27.6 | 0.9 | 0.6 | 3.2 | 0.1 | 0.0 | 0.1 |

*percentages may not sum to 100 due to rounding
Source: U.S. Environmental Protection Agency (EPA) (2018) Emissions & Generation Resource Integrated Database (eGRID) 2016. https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid

## 3.4 Water Delivery Method

The main end use of AWG varies with scale. The large or industrial scale AWGs such as the Water-Gen Large Scale Water Generator, EcoloBlue 1000 series and the Aqua Sciences Emergency Water Station, capable of generating up to 10,000L of water a day, can serve small towns to cities when set up as water stations especially in time of a natural disaster or emergency situations. They can also be used for irrigation of greenhouses, vertical farms and hydroponics. These units are scalable and can be set up in multiples to meet high water needs. In addition, these industrial scale units can be used in schools, hospitals, commercial or residential buildings, whole villages, factories and off-grid settlements. These units can also be installed on the roof tops of buildings and retrofitted to deliver water directly to the kitchen via the internal piping system (Water-Gen). The medium scale units such as the Gen-350 and EcoloBlue 100 series are mobile and can be easily transported for installation for home or business use. The EcoloBlue AWGs can be integrated with portable generators or renewable energy sources (wind, PV) for off-grid usage. The home/office scale AWG units such as Water-Gen Genny and EcoloBlue EB30 series are designed for indoor home or office use to replace bottled water or water fountains. We recommend incorporating a number of scenarios around the power source used, scale, treatment methods used, water delivery methods and the location of use of AWGs. Table 3. Summary of AWG Scenarios provides a list of scenarios that our study will incorporate and the AWGs that are compliant with a given scenario.

The primary water delivery method from the AWGs is filling bottles directly from the unit. Water can be filled in single serve polyethylene terephthalate (PET) plastic bottles for distribution to individuals or in reusable bottles of various sizes including 5 gallon multi-serve polycarbonate water jugs for distribution to a larger community. Alternatively, water can be filled in disposable plastic cups or washable drinking glasses. ERG plans to investigate both reusable and single-use water delivery methods.

**Table 3. Summary of AWG Scenarios**

| | Water-Gen | EcoloBlue | Aqua Sciences |
|---|---|---|---|
| **Power Source** | | | |
| Power grid | ✓ | ✓ | ✓ |
| Diesel Generator | | ✓ | ✓ |
| Renewable power source (wind/solar) | | ✓ | |
| **Scale** | | | |
| Industrial | ✓ | ✓ | ✓ |
| Medium/light industrial | ✓ | ✓ | |
| Home/office | ✓ | ✓ | |
| **Treatment train** | | | |
| Same for all scales | | ✓ | ✓ |
| Unique to each scale | ✓ | | |
| **Water delivery method** | | | |
| Connected to internal piping system | ✓ | | |
| Directly from AWG | ✓ | ✓ | ✓ |
| **Location** | | | |
| Rooftop | ✓ | | |
| Indoors | ✓ | ✓ | |
| Remote (off-grid) | | ✓ | ✓ |
| Water station | ✓ | ✓ | ✓ |

**Commented [JM5]:** Believe WG is intended to use diesel or solar as well

**Commented [JM6]:** Do we even want to go there?

**Commented [JM7]:** WG unit as well

## 4. AWG Life Cycle Inventory Data Requirements

ERG will develop required AWG data through populating the data collection template fields displayed in Table 4 based on the data sources listed in Section 2.4. Where feasible, average, minimum and maximum values will be recorded. Appendix A lists the data ERG has already compiled.

**Table 4. LCI Data Collection Template for AWG units**

| | | | Average Value | Unit | Minimum | Maximum |
|---|---|---|---|---|---|---|
| | | Data Year | | | | |
| | | Technologies evaluated | | | | |
| Inputs | Unit Characteristics | Scale | | L/Water/day | | |
| | | Unit lifetime | | Years | | |
| | | Unit weight | | kg | | |
| | | Maintenance frequency | | Months | | |
| | Material inputs | Steel | | kg | | |
| | | Polymer | | kg | | |
| | | Diesel | | L | | |
| | | Refrigerant | | L | | |
| | | Cleaning solvents | | L | | |
| | | Replacement filters | | #/year | | |
| | Energy inputs | Electricity | | kWh | | |
| | | Diesel (from generator) | | L | | |
| | | Material production | | kWh | | |
| | Transport inputs (AWG manufacture to point of use) | Freight truck | | tkm | | |
| | | Rail | | tkm | | |
| | | Ocean freighter | | tkm | | |
| | | Crane/forklift | | tkm | | |
| Outputs | Products | Potable water | | L/day | | |
| | | Clean Air | | $cm^3$ | | |
| | Losses/wastes | Water | | L/day | | |
| | | Used filters | | #/year | | |
| | | Energy | | kWh | | |
| | Air emissions | VOCs | | g | | |
| | | Particulate matter (diesel generator) | | g | | |
| | | Other emissions (from energy generation) | | g | | |
| | | Other emissions (from material production) | | g | | |
| Cost Data | | Unit cost | | $ | | |
| | | Maintenance cost | | $ | | |

**Commented [JM8]:** Interesting to include



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# 5. Scope of Alternative Bottled Water Analysis

The primary alternative potable water emergency response option that the AWG will be compared to is bottled water. This section lists the planned bottled water systems to be studied, their associated system boundaries, and potential data sources for the analysis.

## 5.1 Systems to be Studied

The comparative bottled water analysis will include both a single-serve and multi-serve option. The main parameters for these two bottled water options in the baseline analysis are displayed in Table 5. The primary packaging option for single-serve bottled water delivery is PET plastic bottles and for the multi-serve large polycarbonate jugs are typically used for home/office delivery (HOD). Two sizes of bottles will be considered in this study; for the single serve option a 500 ml (16.9 oz) PET bottle will be studied and for the multi-serve an 18.9 L (5 gallon) polycarbonate water jug will be studied. The baseline analysis will assume 0% recycled content of the primary bottle material. The single-serve bottles include a polypropylene (PP) closure and are configured in 24-count multipacks with shrink wrap distribution packaging. The HOD bottles are used by consumers in combination with a reusable glass. The single-serve bottles are a single use packaging option; whereas, the HOD bottles have approximately 40 lifetime uses (ORDEQ, 2009). The water within the bottles is modeled as purified municipal water. In many cases, bottled water plants treat municipal water with additional purification steps such as a reverse osmosis, ozone treatment, and UV treatment (ORDEQ, 2009). The percentages of postconsumer waste that are recycled and disposed after use are based on U.S. data from the U.S. EPA "Advancing Sustainable Materials Management Report" (U.S. EPA, 2016). The HOD bottle will be modeled with 100% recycling, since the bottles are managed by delivery services. For all packaging waste that enters the municipal waste stream, 82.2% will be allocated to landfill and 17.8% to waste to energy incineration based on average U.S. conditions (U.S. EPA, 2016).

**Table 5. Bottled Water Systems to be Studied**

| | Single-Serve Water Bottle | Multi-Serve Water Bottle |
|---|---|---|
| **Volume** | 500 ml (16.9 oz) | 18.9 L (5 gallon) |
| **Primary bottle material** | polyethylene terephthalate | polycarbonate |
| **Recycled content** | 0% | 0% |
| **Closure material** | Polypropylene | LDPE |
| **Type of water** | Purified municipal water with reverse osmosis, ozone treatment, and UV. | |
| **Multipack** | 24-count | Not applicable |
| **Multipack packaging** | Shrink wrap | Not applicable |
| **Transport distance*** | 100 mi | 100 mi |
| **Type of reusable drinking container** | Not applicable | 475 ml (16.1 oz) glass |
| **Recycling rate** | 31.3% | 100% |
| **Lifetime uses** | 1 | 40 |

*Transport of bottled water from filling location to the consumer. Transport will be modeled in a diesel combination truck for single-serve bottles. The HOD bottles are transported in smaller vans by a delivery service.

## 5.2 System Boundaries

The system boundaries for the single-serve bottled water analysis are shown in Figure 5. The system boundaries start at municipal drinking water treatment. The bottled water plant conducts additional purification steps prior to filling such reverse osmosis, ozone treatment, and UV treatment. A sensitivity analysis will be included investigating impacts if spring water is sourced instead of municipal treated water. The system boundaries include raw material production of virgin primary and distribution packaging such as PET for the bottle, PP for the cap, LDPE for the shrink wrap and oriented polypropylene (OPP) for the label. A sensitivity analysis is included modeling 10% recycled content of the primary packaging. A corrugated tray is also included as a multipack option in a sensitivity analysis. The baseline model assumes that PET is injection molded to a preform at a separate facility and then stretch blow molded to a bottle at the filling location. After filling and application of the shrink wrap multipack packaging, the bottles are transported to the point of use. The model does not include any refrigeration of the bottled water. Bottles and multipack packaging are either recycled or disposed at end-of-life. Note that all life cycle stages requiring electricity in the bottled water system boundaries will utilize the U.S. average electrical grid fuel mix.

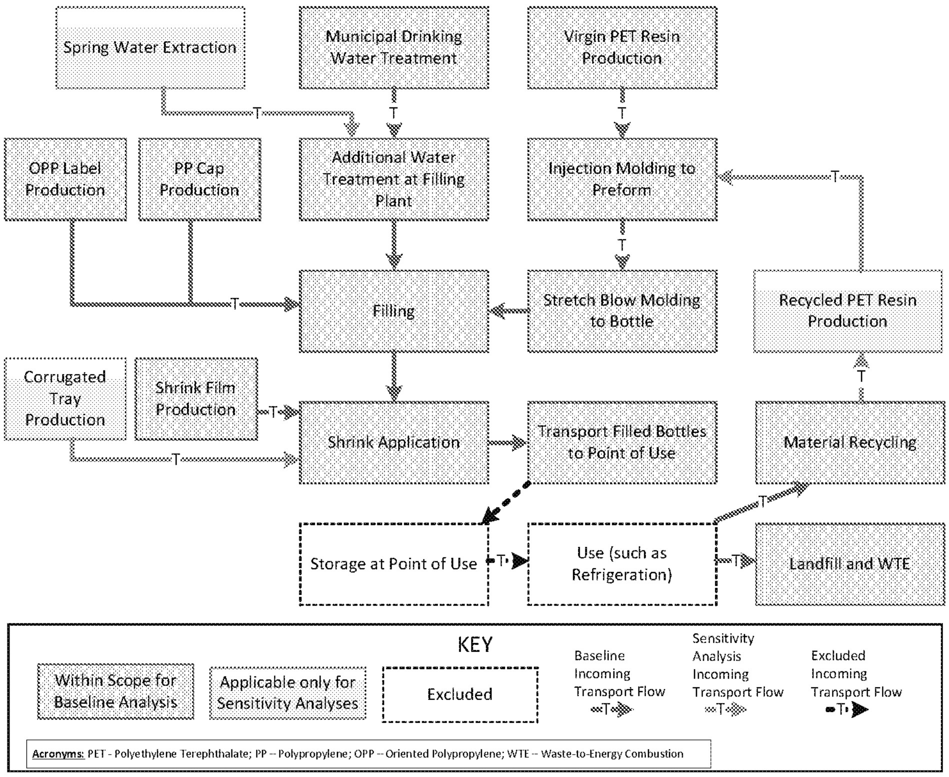


**Figure 5. System Boundaries for Single-Serve Bottled Water Analysis**

The system boundaries for the multi-serve HOD jug/bottle are shown in Figure 6. Water treatment is modeled using the same approach as the single-serve analysis. Filled HOD jugs are transported to point of use via a delivery service van. The baseline analysis assumes consumers use a reusable glass to fill drinking water from the jugs. After use, the glass is cleaned in a dishwasher. This stage includes energy and water use for the dishwashing process, as well as material production of the detergent. Section 5.3 discusses the possibility of including a sensitivity analysis for handwashing instead of dishwashing. After the jug is empty, the same delivery service collects the jug from the point of use. It is assumed the jug cap is disposed and the jug itself is sent back to the filling facility. Prior to filling the jug, the jug goes through an industrial washing process. Industrial washing between uses includes the production of relevant cleaning chemicals. The jugs are used approximately 40 times until they are recycled by the delivery service. It is assumed the reusable glass for drinking is reused for 3 years, once a day, for 1,095 total lifetime uses. Material production requirements for the jug and the reusable glass will be amortized over the useful life of the components.

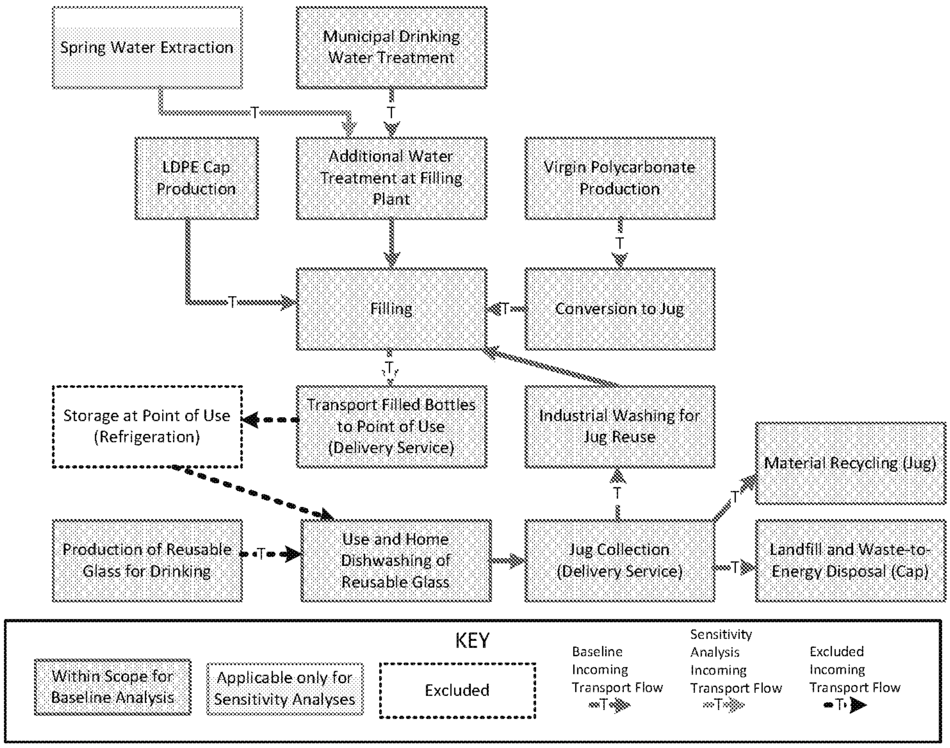


**Figure 6. System Boundaries for Multi-Serve Home Delivery Jug Analysis**

## 5.3 Bottled Water Sensitivity Analysis

We plan to conduct sensitivity analyses for key assumptions in the bottled water analysis. All sensitivity analysis results will be compared to the AWG findings. Recommended sensitivity analyses are listed below.

- **Bottle weight:** single-serve bottle weights vary by brand, with some brands lightweighting PET bottled water packaging. Sampled primary packaging weights for 500 ml bottled water range from 9.3 grams to 23.4 grams. North American brands, most likely used for emergency response conditions, are typically lightweighted in the 500 ml single-serve size. The baseline scenario will model a theoretical lightweight PET bottle (9.5 grams to 11 grams). Sensitivity analyses will be conducted modeling heavier PET bottles. The heavier PET bottles sampled typically represented premium bottled water options such as international spring and artesian water. Bottle weight will not be varied in the multi-serve option.
- **Bottle recycled content and recycling allocation method:** We will model the PET resin for the single-serve bottle as virgin in the baseline analysis. A recycled content up to 10% is often seen in North American single-serve PET water bottles. We recommend

including a sensitivity analysis with up to 10% recycled content in the single-serve bottles. When including recycled content, multiple approaches are available to partition (or allocate) impacts between the useful lives of a material. All recycled content or material recycling will be modeled as cut-off in the baseline analysis. Under this approach, distinct boundaries are drawn between the initial use of the material and subsequent uses of the material after recovery and recycling. All virgin material production burdens are assigned to the first use of the material, and the burdens assigned to the recycled system begin with recovery of the postconsumer material. For containers that are recycled at end of life, all of the burdens for material recovery, transport, separation and sorting, and reprocessing are assigned to the next system using the recycled material. Burdens associated with the final disposal of the product are assigned to the last useful life of the product. We will incorporate an alternative system expansion recycling allocation approach in a sensitivity analysis. In the system expansion approach, the container system boundaries are expanded to include collection and reprocessing of postconsumer containers, as well as the net virgin material displacement or inputs required, based on the balance between the container system's closed-loop recycled content and closed-loop recycling rate. The types and quantities of materials that are displaced by the recovery and secondary processing of post-consumer container material determine the types and quantities of avoided environmental burdens. Inclusion of recycled content will only be modeled in a sensitivity analysis for the single-serve bottle. A recycling allocation sensitivity analysis will be conducted for both the single-serve and multi-serve options.

- **Bottle distribution packaging:** The baseline analysis will include a 24-count multipack configured with shrink wrap. A sensitivity analysis will be conducted to include a corrugated tray in combination with shrink wrap for the single-serve multipack packaging. No distribution packaging will be included for the HOD bottles.
- **Filled bottle transport distance:** The baseline analysis will assume distribution of the filled bottle to the consumer is 100 miles. A sensitivity analysis will be conducted for both the multi-serve and single-serve bottle options varying the transport distance. Both a shorter distance of 50 miles, and a longer distance of 250 miles will be modeled.
- **Bottle water treatment steps:** the baseline analysis will assume the bottle water is derived from municipal water treatment and will include additional water treatment steps at the filling location such as reverse osmosis, ozone treatment, and UV treatment. An alternative source of spring water will be modeled in a sensitivity analysis. Many bottled water brands in the U.S. package spring water, which is from onsite underground formations and is not derived from municipal water treatment. Additionally, water purification steps at the filling plant tend to be less intensive for spring water. In this study, we will assume additional purification steps at the filling plant for spring water include ultrafiltration, UV disinfection, and ozone treatment. This sensitivity analysis will be conducted for both the single-serve and multi-serve options.
- **HOD Jug lifetime uses:** The baseline analysis assumes 40 reuses of the HOD jug. A sensitivity analysis will be conducted varying the number of lifetime uses of the jug. A low estimate of 15 uses and a high estimate of 75 uses will be incorporated in the sensitivity analysis.
- **Reusable glass washing option:** The baseline analysis assumes the reusable glass used in combination with the HOD jug is washed via a dishwasher. A sensitivity analysis will be

conducted assuming the reusable glass is hand washed after use rather than cleaned in a dishwasher.

### 5.4 Data Sources

ERG will develop the bottle water analysis using existing publicly available sources. Initial data sources that have been identified for the bottled water life cycle and production of bottled water packaging materials are as follows:

- **Bottled Water Packaging and Water Treatment:** Garfi, M., Cadena, E., Sanchez-Ramos, D., Ferrer, I. (2016). Life cycle assessment of drinking water: Comparing conventional water treatment, reverse osmosis and mineral water in glass and plastic bottles. Journal of Cleaner Production, Volume 137, Pages 997-1003.
- **Bottled Water Packaging (Single and HOD Containers) and Water Treatment**: Oregon Department of Environmental Quality (ORDEQ). (2009): LCA of Drinking Water Delivery Systems including Bottled Water, Tap Water, and Home-Office Delivery Water, 09-LQ-104.
- **Bottled Water:** Horowitz, N., Frago, J., Mu, D. (2018). Life cycle assessment of bottled water: A case study of Green2O products. https://doi.org/10.1016/j.wasman.2018.02.043 0956-053X
- **Bottled Water Packaging:** Papong, S., Malakul, P., Trungkavashirakun, R., Wenunun, P., Chom-in, T., Nithitanakul, M., Sarobol, E. (2014). Comparative assessment of the environmental profile of PLA and PET drinking water bottles from a life cycle perspective. Journal of Cleaner Production 65, 539-550
- **Municipal Drinking Water Treatment:** Cashman, S., Gaglione, A., Mosley, J., Weiss, L., Ashbolt, N., Hawkins, T., Cashdollar, J., Xue, X., Ma, C., and Arden, S. (2014). Environmental and cost life cycle assessment of disinfection options for municipal drinking water treatment. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-14/376.
- **PET, LDPE, PP, HDPE Virgin Resin**: American Chemistry Council (ACC). (2011a). Cradle-to-Gate LCI of Nine Plastic Resins and Two Polyurethane Precursors. Franklin Associates, A Division of ERG. http://plastics.americanchemistry.com/LifeCycle-Inventory-of-9-Plastics-Resins-and-4-Polyurethane-Precursors-Rpt-Only
- **PET Recycled Resin:** Franklin Associates. (2011). Life Cycle Inventory of 100% Postconsumer HDPE and PET Recycled Resin from Postconsumer Containers and Packaging.
- **Plastic Conversion Processes**: ACC. (2011b). Life Cycle Inventory of Plastic Fabrication Processes: Injection Molding and Thermoforming. Franklin Associates, A Division of ERG. https://plastics.americanchemistry.com/Education-Resources/Publications/LCI-of-Plastic-Fabrication-Processes-Injection-Molding-and-Thermoforming.pdf.
- **Corrugated Material Production:** National Council for Air and Stream Improvement. (2014). Life Cycle Assessment of U.S. Average Corrugated Product.

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**APPENDIX A – AWG DATA COMPILED**
**Provided in Separate Excel Document**